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POTENTIAL GREAT LAKES HYDROLOGY AND LAKE LEVEL IMPACTS RESULTING FROM GLOBAL WARMING

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1. INTRODUCTION

We must understand climatic change impacts on Laurentian Great Lakes water supply components, and on basin storages of water and heat, before we can assess secondary impacts. The Great Lakes Environmental Research Laboratory (GLERL) constructed system-wide hydrological models of the Great Lakes (*Croley*, 1994a.b) for studying regional effects of climate changes. Here, we review recent climate impact research and identify problems with that methodology. We utilize climate transposition to ameliorate these problems, and estimate the effects of transposing four southwestern climes to the Great Lakes Basin.

2. GREAT LAKES CLIMATE IMPACT STUDIES

Preliminary impact estimates considered simple constant changes in air temperature or precipitation. *Quinn and Croley* (1983) estimated net basin supply to Lakes Superior and Erie. *Cohen* (1986) estimated net basin supply to all Great Lakes. *Quinn* (1988) estimated water lowering due to decreases in net basin supplies on Lakes Michigan, Huron, St. Clair, and Erie.

Researchers have run general circulation models (GCMs) of the earth's atmosphere to simulate climates for current conditions and for a doubling of global carbon dioxide levels (2xCO_2). They used a larger-than-regional scale for many internally consistent daily meteorological variables. The US Environmental Protection Agency (*USEPA*, 1984) and *Rind* (personal communication, 1988) used the hydrologic components of general circulation models. They assessed changes in water availability in several regions throughout North America, but the regions were very large. Rind used only four regions for the entire continent and indicated needs for smaller region assessments.

Regional hydrological models can link to GCM outputs to assess changes associated with climate change scenarios. *Allsopp and Cohen* (1986) used Goddard Institute of Space Sciences (GISS) 2xCO_2 climate scenarios with net basin supply estimates. The US Environmental Protection Agency (EPA), at the direction of the US Congress, coordinated several regional studies of the potential effects of a 2xCO_2 atmosphere (*USEPA*, 1989). They directed others to consider alternative climate scenarios by: 1) changing historical meteorology (similar to the changes observed in GCM simulations of 2xCO_2), 2) observing changed process model outputs, and 3) comparing to model results from unchanged data. *Cohen* (1990, 1991) discusses other studies that use this type of linkage methodology and also discusses his concerns for comparability between studies using different types.

As part of the EPA study, GLERL assessed changes in Great Lakes hydrology consequent with simulated 2xCO_2 atmospheric scenarios from three GCMs (*Croley*, 1990; *Hartmann*, 1990; *USEPA*, 1989). EPA required that GLERL first simulate 30 years of "present" Great Lakes hydrology as a base case, with a 3-year initialization period, by using historical daily data with present diversions and channel conditions. GLERL arbitrarily set initial conditions but used an initialization period to allow their models to converge to conditions initial to the simulation. GLERL repeated their simulation, with initial conditions set equal to the averages over the simulation period, until these averages were unchanging. This facilitated investigation of "steady-state" conditions. Then GLERL conducted simulations with adjusted data sets. EPA obtained output from atmospheric GCM simulations, representing both "present" and 2xCO_2 steady-state conditions, from GISS, the Geophysical Fluid Dynamics Laboratory (GFDL), and the Oregon State University (OSU). They supplied monthly adjustments of 2xCO_2 to "present" for each meteorological variable. GLERL applied them to their daily historical data sets to estimate 33-year sequences of atmospheric conditions associated with the 2xCO_2 scenarios. GLERL then used the 2xCO_2 scenarios in hydrology impact model simulations similar to those for the base case scenario. They interpreted differences between the 2xCO_2 scenario and the base case scenario as resulting from the changed climate.

The EPA studies, in part, and the high water levels of the late 1980s prompted the International Joint Commission (IJC) to reassess climate change impacts on Great Lakes hydrology and lake thermal structure.

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GLERL adapted EPA methodology for the IJC studies (*Croley*, 1992) to consider $2xCO_2$ GCM scenarios that were supplied by the Canadian Climate Centre (CCC) for the period 1948-88. GLERL's procedure to estimate "steady-state" suggested, for a few subbasins, very different initial groundwater storages than were used in model calibrations. Since we have little confidence in large groundwater half-life calibrations from only 10 to 20 years, we used initial values, used in calibrations, also in the simulations for those subbasins.

The CCC supplied average monthly meteorological outputs for each month of the year as resulting from their second-generation GCM; see *Croley* (1992). GLERL computed $2xCO_2$ monthly adjustments at each location and used them with historical data to estimate the $2xCO_2$ 41-year sequences for each Great Lake basin. Then GLERL used the $2xCO_2$ scenario in simulations similar to the base case as before.

Other EPA studies included partial assessments of large-lake heat storage associated with climate change on Lakes Michigan and Erie (*USEPA*, 1989). The IJC study looked in less detail but more breadth at large-lake thermodynamics; while GLERL considered only lake-wide effects, they assessed all lakes.

3. GCM LINKAGE PROBLEMS

People should receive the EPA and IJC studies with caution since the results are dependent on GCM outputs with inherent large uncertainties. Transfer of information between the GCMs and GLERL's hydrologic models involves several assumptions. The transfer assumes that solar insolation at the top of and through the atmosphere on a clear day is unchanged under the changed climate; only cloud cover changes modify it. GCM outputs forced the use of inappropriately large spatial and temporal scales for GLERL models. GLERL used daily time intervals and subbasin areas averaging 4,300 km^2. GCM adjustments exist at monthly time intervals and grids of 7.83° latitude by 10° longitude (GISS), 4.44° by 7.5° (GFDL), 4° by 5° (OSU), and 3.75° by 3.75° interpolated to 1° by 1°(CCC GCM). GLERL's procedure for transferring information from a GCM grid is an objective but simple approach; it ignores the interdependencies that exist between the various meteorological variables as all are averaged independently in the same manner. Of secondary importance, the spatial averaging of meteorological values over a box centered on a GCM grid point filters all variability that exists in the GCM output over that box. Furthermore, much of the variability at the smallest resolvable scale of GCMs is, unfortunately, spurious.

Spatial and temporal (inter-annual, seasonal, and daily) variabilities are the same in the adjusted data sets ($2xCO_2$ scenarios) as in the historical period (base case). This is a result of applying simple ratios or differences to calculate $2xCO_2$ scenarios from base case scenarios. This implicitly ignores spatial and temporal phase and frequency changes consequent in the $2xCO_2$ GCM simulations. For example, a changed climate alters the movement (direction, speed, frequencies) of air masses over the lakes. This implies an alteration of the seasonal temporal structure for storms and cyclonic events as well as the intensities of storms. The above method only allows modification of the latter. Seasonal changes induced by the changed meteorology because of a time-lag storage effect are observable, however. Shifts in snowpack or in the growth and decay of water surface temperatures are examples. Changes in annual variability are less clear, again because the historical time structure is unchanged.

4. CLIMATE TRANSPOSITION

While the EPA and IJC studies looked at changes in the mean values of hydrologic variables, they did not address changes in ***variability***. This variability is the singular key problem for shipping, power production, and resource managers. GLERL and the Midwest Climate Center (MCC) recognized the importance of shifts in the daily, seasonal, interannual, and multi-year climate variability of lake supplies, as well as shifts in mean supplies. They investigated these changes in variability by utilizing data for climates that actually exist to the south and west of the Great Lakes and that resemble some of the $2xCO_2$ GCM scenarios. Lengthy (at least 40 years) and detailed records of ***daily*** weather at about 2,000 sites are available to represent physically plausible and coherent scenarios of alternative climates. Such data sets incorporate reasonable values and frequencies of extreme events, ensuring representation and transposition of desired temporal and spatial variabilities over the Great Lakes.

We considered four separate climatic regimes based on published $2xCO_2$ GCM ranges. Scenario 1 (warm and dry) corresponds to low temperature and precipitation ranges. Scenario 2 (warm and wet) corresponds to low temperature and high precipitation ranges. Scenario 3 (very warm and dry) corresponds to high temperature and low precipitation ranges. Scenario 4 (very warm and wet) corresponds to high temperature and precipitation ranges. Inspection of available data assigned to scenario 1 data transposed to the Great Lakes Basin from 6°S and 10°W; scenario 2 is 6°S x 0°W; scenario 3 is 10°S x 11°W; and scenario 4 is 10°S x 5°W. MCC supplied daily data and GLERL transposed them to the Great Lakes. We relocated all meteorological station data and Thiessen-weighted to obtain areal averages over the 121 watersheds and 7 lake surfaces for all days of record (1948-1992). GLERL also reduced all historical data (base case) within the Great Lakes (1900-1990). This involved error checking and data correction for thousands of stations, and regeneration of areal averages.

The Great Lakes affect the climate near the shoreline but these effects are not present in transposed data sets. MCC prepared maps of generalized seasonal lake effects on the area's meteorology, to be applied to the transposed climates. GLERL applied these corrections to scenario 3 (identified as scenario 5); however, these corrections did not significantly alter the results. We deem further correction unnecessary and do not present scenario 5 here.

GLERL estimated the Great Lakes hydrology of each transposed climate as before, by applying the system of hydrological models to these data sets directly and comparing outputs for each transposed climate to a base case derived with the models from historical meteorological data. This approach allows preservation of reasonable spatial and temporal variations in meteorology and preserves the interdependencies that exist between the various meteorological variables. It also allows the use of appropriate spatial and temporal scales, better matching the models than do the GCM output corrections.

The sections that follow give annual average estimates for both means and standard deviations for selected variables. The entire daily time series and the average annual cycles (daily values) for the means and standard deviations for each of these (and other) variables are available separately (*Croley et al.*, 1994).

4.1 *Mean Hydrology Differences*

Table 1 summarizes climate change impact differences between the base case and each scenario. While scenarios 3 and 4 are warmer than 1 and 2 for all lake basins (refer to *Overland Air Temperatures* in Table 1), there is not as clear a division in precipitation across all lake basins. Lake Superior, being the western-most lake, receives the driest (most-western) part of each of the transposed climates and shows the smallest precipitation of all lakes for all transposed scenarios. Precipitation increases for all scenarios for lakes lying in a southeasterly direction.

The air temperature pattern repeats in water surface temperatures (refer to *Water Surface Temperatures* in Table 1) and consequently in lake evaporation (refer to *Evaporation* in Table 1) with scenarios 3 and 4 yielding higher average values than 2 and 4 for all lakes. The increased air and water temperatures reflect changes not shown here. All scenarios almost completely eliminate snow packs on all lake basins, ranging from decreases of 86% to 99%. Lake heat storage increases for all scenarios, ranging from 23% to 157%. This eliminates much dimictic behavior (water column turnovers would occur once a year instead of twice and would be shallower).

The western-most scenarios, 1 and 3, are similar to each other on Lake Superior with 3 being slightly more extreme. The negative total net basin supplies for these scenarios (relative changes < -100%) are the most striking figures. They imply that the lake is emptying since there is a net loss of water there. Lower precipitation and runoff and higher evaporation reveal a hotter, drier climate as compared to the base. Scenarios 2 and 4 also show decreases on Lake Superior (as compared to the base) in runoff but not in precipitation. The increases in evaporation are large but not large enough to result in a negative net basin supply for either scenario.

The various scenarios look very different on the Michigan, Huron, and Georgian Bay basins. In the western-most scenarios, 1 and 3, evaporation is still much higher than the base. On Lake Huron, increases in precipitation offset decreases in runoff. On Lake Michigan and Georgian Bay, runoff decreases are, for the most part, greater than precipitation increases. Net basin supplies drop but do not become negative (relative changes are negative but less than 100%). For scenarios 2 and 4, all parameters increase compared to the base case on Lakes Michigan and Huron; precipitation and evaporation changes, are impressive. However, on Georgian Bay, while precipitation and evaporation also increase impressively, drops in runoff lower net basin supplies.

In the Erie basin, all hydrologic parameters increase for each scenario as compared to the base, except for a slight decrease in net basin supply under scenario 3. Net basin supplies for scenarios 2 and 4 are up 74% and 45% respectively. Scenario 2 increases net basin supply the most, with the smallest increase (over the base) in evaporation. On Lake Ontario, both precipitation and evaporation increase for all scenarios, but drops in runoff allow net basin supplies to drop a little for scenarios 1, 2, and 4. A slight increase in runoff for scenario 3 allows net basin supply to increase a little there.

4.2 *Hydrology Variation Differences*

Table 2 presents selected variation changes for annual statistics only; *Croley et al.* (1994) discuss seasonal changes elsewhere. As seen in Table 2 (refer to *Overland / Overlake Precipitation*), the standard deviation of annual precipitation exceeds the base case on all lake basins for all scenarios. It ranges from its smallest values in scenario 2 on Georgian Bay (17%

TABLE 1. Average Annual Steady-State Climate Impacts

Basin	Overland Air Temperature(°C) & Transferred Climate Absolute Differences[a]				
	BASE	#1	#2	#3	#4
Superior	2.3	6.9	6.8	10.4	10.9
Michigan	7.2	6.3	5.6	9.8	9.4
Huron	7.1	5.8	4.6	9.8	9.1
Georgian	4.3	7.0	5.7	10.4	9.8
Erie	9.1	6.1	4.4	9.4	8.2
Ontario	7.2	6.2	6.5	9.3	9.7

Basin	Overland/Overlake Precipitation (mm) & Transferred Climate Relative Changes[a]				
	BASE	#1	#2	#3	#4
Superior	817	-23%	6%	-20%	21%
Michigan	828	3%	39%	1%	59%
Huron	813	26%	40%	48%	70%
Georgian	908	2%	10%	30%	47%
Erie	913	31%	44%	37%	55%
Ontario	934	26%	18%	49%	33%

Basin	Runoff as Overlake Depth (mm) & Transferred Climate Relative Changes[a]				
	BASE	#1	#2	#3	#4
Superior	615	-57%	-27%	-62%	-31%
Michigan	645	-28%	23%	-34%	29%
Huron	390	-9%	21%	5%	39%
Georgian	1803	-37%	-20%	-20%	0%
Erie	810	26%	48%	17%	36%
Ontario	1701	-1%	-14%	9%	-22%

Basin	Water Surface Temperature (°C) & Transferred Climate Absolute Differences[a]				
	BASE	#1	#2	#3	#4
Superior	5.5	5.1	5.9	7.5	9.2
Michigan	8.7	4.1	4.6	7.4	9.0
Huron	8.0	5.0	5.4	9.7	9.5
Georgian	7.7	5.5	5.2	10.2	9.3
Erie	11.0	6.2	4.8	8.9	7.8
Ontario	8.6	6.1	5.6	10.2	9.2

Basin	Evaporation as Overlake Depth (mm) & Transferred Climate Relative Changes[a]				
	BASE	#1	#2	#3	#4
Superior	569	61%	57%	94%	91%
Michigan	640	39%	20%	65%	54%
Huron	612	48%	28%	74%	70%
Georgian	634	57%	36%	85%	75%
Erie	895	44%	20%	56%	47%
Ontario	645	42%	21%	68%	66%

Basin	Net Basin Supply as Overlake Depth (mm) & Transferred Climate Relative Changes[a]				
	BASE	#1	#2	#3	#4
Superior	863	-103%	-51%	-125%	-62%
Michigan	833	-50%	42%	-75%	39%
Huron	590	-21%	40%	-7%	50%
Georgian	2076	-49%	-24%	-30%	-3%
Erie	828	13%	74%	-2%	45%
Ontario	1990	-2%	-11%	9%	-24%

[a]Scenario 1 is 6°S by 10°W of the Great Lakes; #2 is 6°S × 0°W; #3 is 10°S × 11°W; and #4 is 10°S × 5°W.

larger than the base case) to its largest value in scenario 4 on Lake Huron (154% larger than the base case). Scenarios 3 and 4 generally have the largest annual variability. These scenarios are the warmest, with a corresponding generally sparser nature of precipitation. Runoff and net basin supply (refer to *Runoff* and *Net Basin Supply* in Table 2) repeat this pattern of variability somewhat. Scenarios 3 and 4 appear generally more variable, on an annual basis, than do 1 and 2 with regard to precipitation, runoff and net basin supply. This generally is not the case with regard to evaporation. This results largely from scenaros 3 and 4 having generally more evaporation than 1 and 2 (refer to *Evaporation* in Table 1); actual variation is similar, relative to the mean, among all scenarios.

Note that most scenarios vary more than the base case, with regard to all variables in Table 2 (relative changes are positive). The smaller variation in evaporation on Lake Erie for all scenarios (negative relative changes) probably reflects the nature of the lake. It is a shallow lake with the largest evaporation of all lakes presently (see *Evaporation* in Table 1). Higher evaporation rates under each of the scenarios are approaching limiting values; this narrows the range of values and the standard deviation.

4.3 *Integrative Great Lakes Indices*

We summed the precipitation, basin evapotranspiration (not shown in Tables 1 or 2), runoff, lake evaporation, and net basin supplies across all basin and lakes in the Great Lakes basin, as summarized in Table 3. It is much easier to see the correspondence to transposed climate with such a large spatial averaging. Scenarios 2 and 4 are the wettest (see *Overland Precipitation* and *Overlake Precipitation* in Table 3), producing more runoff than 1 and 3 (see *Basin Runoff* in Table 3). Overlake evaporation is highest for scenarios 3 and 4 (the warmest climes) but the pattern of net basin supply changes follows the precipitation pattern and scenarios 2 and 4 result in the largest supplies. Even so, all net basin supplies are smaller than the base case.

We used the net basin supplies calculated for each scenario to drive the Great Lakes routing models, Plan 92HQ for Superior through Erie and Plan 58HQ for Ontario (*Croley et al.*, 1994). We then ran the routing models to steady state for each scenario. As flows between Georgian Bay, Lake Huron, and Lake Michigan are large, we treat the three together as one lake hydraulically, referred to here as Lake Michigan-

TABLE 2. Average Annual Steady-State Climate ***Variations***

Basin	Overland/Overlake Precipitation (mm) & Tranferred Climate Std. Dev. Rel. Change[a]					Runoff as Overlake Depth (mm) & Transferred Climate Std. Dev. Rel. Change[a]				
	BASE	#1	#2	#3	#4	BASE	#1	#2	#3	#4
Superior	83.8	27%	41%	52%	110%	60	-1%	24%	6%	65%
Michigan	93.8	84%	64%	64%	124%	88	35%	57%	-6%	96%
Huron	89.1	127%	52%	153%	154%	61	64%	40%	51%	147%
Georgian	93.8	76%	17%	114%	101%	198	9%	-26%	49%	69%
Erie	109.7	99%	51%	105%	103%	149	81%	58%	81%	108%
Ontario	89.6	99%	71%	149%	96%	204	115%	60%	151%	67%

Basin	Evaporation as Overlake Depth (mm) & Transferred Climate Std. Dev. Rel. Change[a]					Net Basin Supply as Overlake Depth (mm) & Transferred Climate Std. Dev. Rel. Change[a]				
	BASE	#1	#2	#3	#4	BASE	#1	#2	#3	#4
Superior	59.4	14%	12%	20%	3%	164	21%	32%	39%	80%
Michigan	67.3	4%	1%	8%	-6%	203	62%	53%	38%	100%
Huron	64.1	11%	15%	7%	9%	165	103%	47%	108%	133%
Georgian	62.0	19%	13%	12%	8%	303	30%	-17%	65%	70%
Erie	78.5	-43%	-25%	-33%	-35%	268	87%	51%	86%	99%
Ontario	60.2	13%	15%	-3%	9%	304	102%	57%	141%	74%

[a]Scenario 1 is 6°S by 10°W of the Great Lakes; #2 is 6°S × 0°W; #3 is 10°S × 11°W; and #4 is 10°S × 5°W.

Huron. This is necessary since these flows are unknown. We present annual average lake levels for all lakes in Table 4.

Lake levels on the upper lakes, under both scenarios 2 and 4, appear slightly lower than the base case by less than one meter. The levels of Lake Erie were virtually unchanged and Lake Ontario is down slightly, from one-quarter meter (scenario 2) to over one-half meter (4). It is worth noting that even under scenario 2, the least extreme of all four scenarios, Lake Superior is down 76 cm and Michigan-Huron and Ontario are lower by over 20 cm. Scenario 4 offers more pronounced effects on outflows than does 2; see Table 4. Both scenarios halve the outflow from Lake Superior. Both scenarios also reduce slightly the outflows from Lake Michigan-Huron and Ontario but leave the outflow from Lake Erie almost unchanged.

The impacts on levels and flows were more dramatic for scenarios 1 and 3, with the most severe impacts on Lake Superior. In scenario 3, the mean level of Lake Superior drops over 11 meters compared to the base run. In scenario 1, Lake Superior levels drop an average of about 2 meters. Lake Superior outflow stops completely; although for scenario 1, this happens after a few years of low flows. This corresponds to Lake Superior becoming a terminal lake. Although it appears Superior dries up, we are actually beyond the capabilities of our hydrological models. We can only say that the lake level drops are severe. Under both scenarios, Lake Michigan-Huron drops over 3 meters and Lakes Erie and Ontario drop over 2 meters. Outflow from Lake Michigan-Huron is about one third of normal. Outflows are slightly better (about 40% of normal) from Lake Erie and just over 50% of normal out of Lake Ontario.

Changes in lake level variability were pronounced but are not shown here. In general, lake levels on all lakes were more variable for all scenarios as compared to the base case.

5. SUMMARY

We transposed 4 climates from the southwest to the Great Lakes. This incorporates natural variabilities not possible with GCM-generated corrections to

TABLE 3. Average Annual Steady-State Great Lakes Basin Hydrology Summary

Scenario	Overland Precipitation ($m^3 s^{-1}$)		Evapo-transpiration ($m^3 s^1$)		Basin Runoff ($m^3 s^1$)		Overlake Precipitation ($m^3 s^1$)		Overlake Evaporation ($m^3 s^1$)		Net Basin Supply ($m^3 s^1$)	
Base	13855		7814		6206		6554		4958		7803	
6°S × 10°W	14643	*+6%*	10201	*+31%*	4674	*-25%*	6767	*+3%*	7394	*+49%*	4048	*-48%*
6°S × 0°W	17167	*+24%*	11198	*+43%*	6154	*-1%*	8169	*+25%*	6615	*+33%*	7708	*-1%*
10°S × 11°W	16236	*+17%*	11563	*+48%*	4877	*-21%*	7379	*+13%*	8699	*+75%*	3556	*-54%*
10°S × 5°W	20095	*+45%*	13907	*+78%*	6308	*+2%*	9482	*+45%*	8364	*+69%*	7426	*-5%*

TABLE 4. Average Annual Steady-State Lake Level and Outflow Changes

Basin	Mean Annual Lake Level (m) & Transferred Climate Absolute Differences[a]					Mean Annual Lake Outflows ($m^3 s^{-1}$) & Transferred Climate Relative Changes[a]				
	BASE	#1	#2	#3	#4	BASE	#1	#2	#3	#4
Superior	183.17	-2.12	-0.75	-11.30	-0.97	2390	-96%	-48%	-100%	-58%
Michigan-Huron	176.65	-3.33	-0.23	-3.49	-0.23	5818	-66%	-9%	-68%	-7%
Erie	174.32	-2.14	+0.01	-2.28	-0.04	6642	-56%	+1%	-59%	-1%
Ontario	74.66	-1.50	-0.03	-1.52	+0.03	7848	-48%	-1%	-48%	-4%

[a]Scenario 1 is 6°S by 10°W of the Great Lakes; #2 is 6°S × 0°W; #3 is 10°S × 11°W; and #4 is 10°S × 5°W.

historical data, as used elsewhere. We determined daily runoff and lake evaporation over 43-year periods with GLERL's models to estimate water supplies and routed them to simulate lake levels and connecting channels' outflows. Air temperatures increased 4 to 11°C and precipitation ranged from -23% to +70%, resulting in lake water supply changes of -103% to +74%. Water supplies decreased dramatically for the two driest scenarios with Lake Superior becoming a terminal lake. Also, lake level variability increased for all lakes for most of the scenarios.

6. ACKNOWLEDGMENT

This work was partially supported by the National Oceanic and Atmospheric Administration grant no. NA16WN0351 at The Great Lakes Environmental Research Laboratory and The Midwest Climate Center. This paper is GLERL contribution no. 931.

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SIXTH SYMPOSIUM ON GLOBAL CHANGE STUDIES

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Front Cover: The annual mean surface skin temperature for 1988 and the difference between 1988 and 1987. These fields were retrieved from analysis of HIRS2/MSU sounding data, as taken from the TOVS Pathfinder Path A data set. Results, shown on a 1° x 1° latitude-longitude grid, are from NOAA 10 and correspond to the average of the 7:30 A.M. and 7:30 P.M. local time soundings. The 7:30 A.M., P.M. average annual mean surface skin temperature for 1988 was 287.31K. 1988 was a pronounced La Nina year, containing a prominent local minimum sea surface temperature in the eastern equatorial Pacific Ocean. 1987 was a modest El Nino year. The negative differences over the equatorial Pacific Ocean, tropical land, and Canada are compensated by positive differences over Eurasia, Australia, and Antarctica. The annual mean surface skin temperature for 1988 was 0.01°C warmer than that of 1987. Analysis of the entire TOVS Pathfinder 16 year data set 1979-1995 is expected to be completed by 1996. Results will also include atmospheric temperature and moisture profiles, total O_3 column burden, cloud heights and amounts, OLR and Longwave Cloud Radiative Forcing, and precipitation estimate. Figures courtesy of Joel Susskind and Robert Atlas, NASA/Goddard Space Flight Center, Laboratory for Atmospheres, Satellite Data Utilization Office.

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